Information Processing with Quantum Gravity

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Abstract: The theory of quantum gravity is aimed to fuse general relativity with quantum theory into a more fundamental framework. In this work, we provide a model for the information processing structure of quantum gravity.

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1. Introduction

In general relativity, processes and events are causally non-separable because the causal structure of space-time geometry is non-fixed. In a non-fixed causality structure, the sequence of time steps has no interpretable meaning. In our macroscopic world, events and processes are distinguishable in time and, thus, causally separable because the space-time geometry has a deterministic causality structure [1-4]. The meaning of time evolution is also non-vanishing and has an interpretable notion in the microscopic world of quantum mechanics. It is precisely the reason why classical and quantum computations are evolved by a sequence of time steps and why the term time has an interpretable and plausible meaning in the macro- and microscopic levels. A fundamental difference between the nature of events of general relativity and quantum mechanics is that although the theory of general relativity provides a non-fixed causal space-time structure with deterministic events, in quantum mechanics, the space-time geometry has a fixed, deterministic causality structure whereas the events are nondeterministic. Quantum gravity is provided to fill the gap between these two fundamentally different theories. In the quantum gravity space, the computations and the information processing steps are interpreted without the notion of time evolution. This space-time structure allows us to perform quantum gravity computations and to build quantum gravity computers, which fuse the extreme power of quantum computations and the non-fixed causality structure of general relativity [2].

We show that the quantum gravity environment is an information resource-pool from which valuable information can be extracted. We analyze the structure of the quantum gravity space and the entanglement of the space-time geometry. We study the information transfer capabilities of quantum gravity space and define the quantum gravity channel. We reveal that the quantum gravity space acts as a background noise on the local environment states. We characterize the properties of the noise of the quantum gravity space and show that it allows the separate local parties to simulate remote outputs from the local environment state, through the process of remote simulation. We characterize the information transfer of the gravity space and the correlation measure functions of the gravity channel. We investigate the process of stimulated storage for quantum gravity memories, a phenomenon that exploits the information resource-pool property of quantum gravity. The results confirm the perception that the benefits of the quantum gravity space can be exploited in quantum computations, particularly in the development of quantum computers.

2. Information resource-pool property of quantum gravity

As we have revealed, the quantum gravity environment acts as a noisy map on the local environment state and behaves as an information resource-pool for the local parties. In particular, from the local environment E_i, the remote output B_j can be simulated via the local map $\mathcal{M}_{\mathcal{D}}$ as $B_j = E_i \circ \mathcal{D}^{E_i \to B_j}$ with probability $p > \frac{1}{2}$. The model of remote simulation in the quantum gravity environment is summarized in Fig. 1. The local outputs and environment states are referred to as B_i, E_i, $i = 1,2$, respectively. The quantum gravity setting allows the parties with a probability of $p > \frac{1}{2}$ to simulate the remote output from the local environment state through the local degrading map $\mathcal{D}^{E \to B}$. Alice can simulate B_2 from her local environment state E_1 as $B_2 = E_1 \circ \mathcal{D}^{E_1 \to B_2}$, whereas Bob can simulate Alice's output B_1 as $B_1 = E_2 \circ \mathcal{D}^{E_2 \to B_1}$. The quantum gravity acts as a noise on the local environments; thus, it behaves as an information resource-pool for the local parties about the remote CPTP (Completely Positive Trace Preserving) maps.

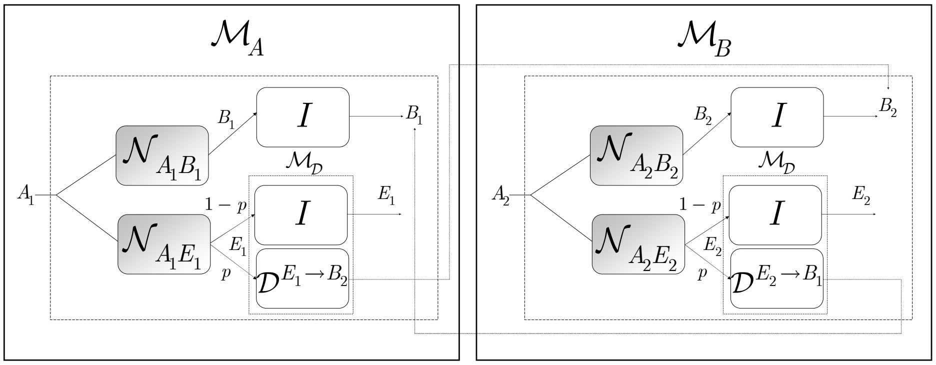

Figure 1. The information resource-pool property of quantum gravity. The local CPTP maps $\mathcal{M}_A$ and $\mathcal{M}_B$ are independent, physically separated maps; the inputs A_1 and A_2 are uncorrelated variables conveying classical or quantum information; and $\mathcal{D}^{E_1\to B_2}$ and $\mathcal{D}^{E_2\to B_1}$ are local CPTP maps (called *local degrading maps* or *background noise* of quantum gravity).

3. Information transfer of quantum gravity

The quantum gravity environment allows the transfer of classical and quantum information between the local maps $\mathcal{M}_A$ and $\mathcal{M}_B$. The information flow is realized through the quantum gravity environment $\mathcal{G}_E$ (entangled space-time geometry) via the partition $\mathcal{G}_E - E_iB_j$ of the tripartite system $\rho_{\mathcal{G}_E E_i B_j}$. The correlation measure can be settled between subsystems $\mathcal{G}_E E_i$ and $\mathcal{G}_E B_j$. For simplicity, we will use $\mathcal{G}_E E_1$ throughout to characterize exactly the information transmission between the local environment states and the quantum gravity environment state. The results of the correlation measure analysis are summarized in Fig. 2.

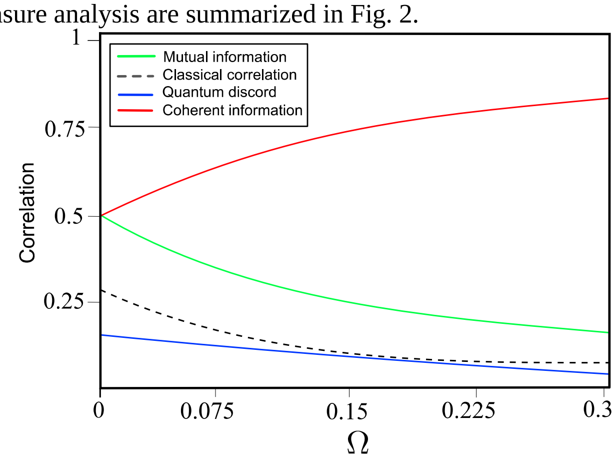

Figure 2. The correlation measures between the quantum gravity environment $\mathcal{G}_E$ and the local environment E_1, evaluated on $\rho_{\mathcal{G}_E E_1}$, in function of Ω, $\Omega \leq 1/3$. As Ω increases, the quantum influences become stronger, and the coherent information strongly increases. (The coherent information is shown in the absolute value.)

4. Conclusions

In this work, we provided a model for the information processing structure of the quantum gravity space. We analyzed the connection of the gravity environment with the local processes and revealed that the quantum gravity environment is an information transfer device. This property makes the use of quantum gravity space as an information resource-pool available for the parties. We introduced the term remote simulation and showed that the quantum gravity space induces noise on the local environment states, which allows the parties to simulate locally separated remote systems.

5. References

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